Lidars calibration and metrology

Black & White methodologies in a standardised field

Borraccino, Antoine

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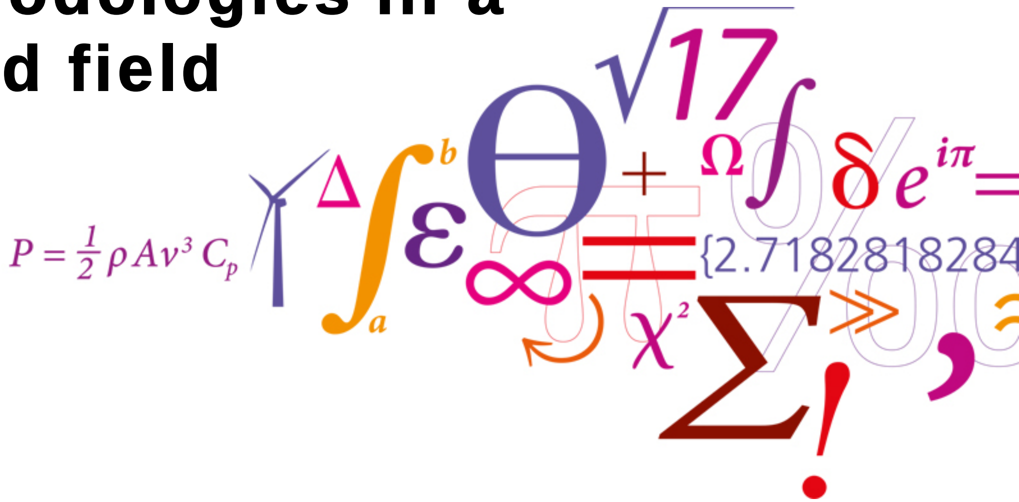
Antoine Borraccino

Lidars calibration and metrology

Black & White methodologies in a standardised field



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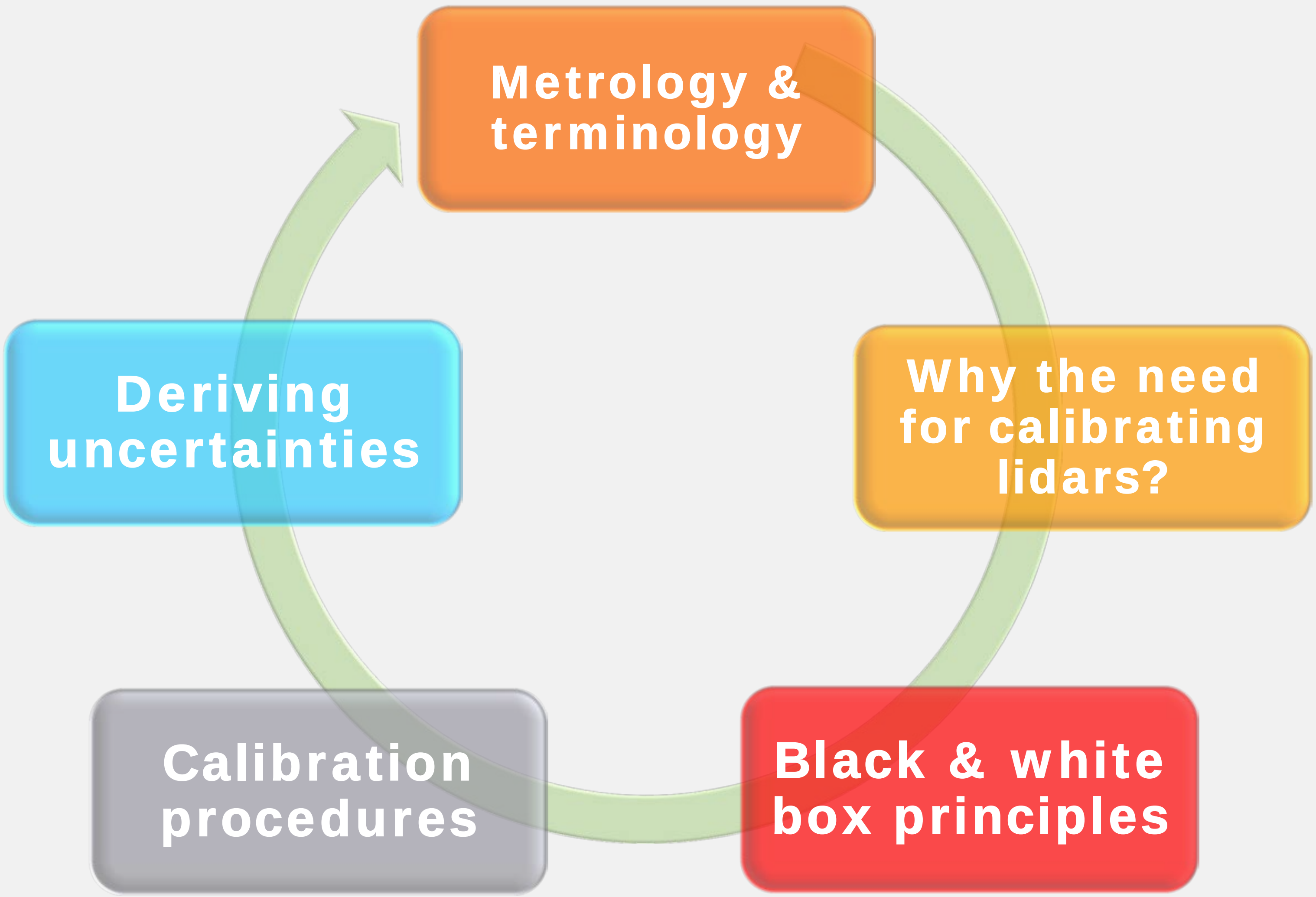
Department of Wind Energy

Outline


Metrology & terminology
Why the need for calibrating lidars?
Black & white box principles
Calibration procedures
Deriving uncertainties

Metrology and terminology (1/3)

- **Metrology** is a standardised field
  - JCGM: Joint Committee for Guides in Metrology (BIPM, IEC, ISO, etc)
    - GUM ➔ uncertainties
    - VIM ➔ international vocabulary of metrology
  - Following definitions refer to VIM (JCGM 200:2012)

- **Verification:** *”provision of objective evidence that a given item fulfills specified requirements”*

  - An item can be a :
    - Process

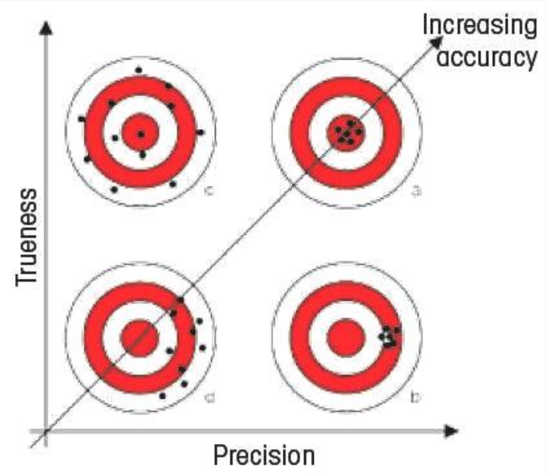
    ➔ e.g. an algorithm applied to a Doppler frequency spectra
    - Material
    - Measurement procedure or measuring system

    ➔ e.g. related to performances or if a measurement uncertainty can be met

Metrology and terminology (2/3)

- **Validation:** *"verification, where the <u>specified</u> requirements are adequate for an intended use"*

- **Trueness, precision, accuracy:**



  - **<u>Trueness</u>**: closeness between averaged measured and averaged reference values over a large/infinite number of samples ➔ Not a quantity

    ➔*"inversely related to systematic measurement error"*

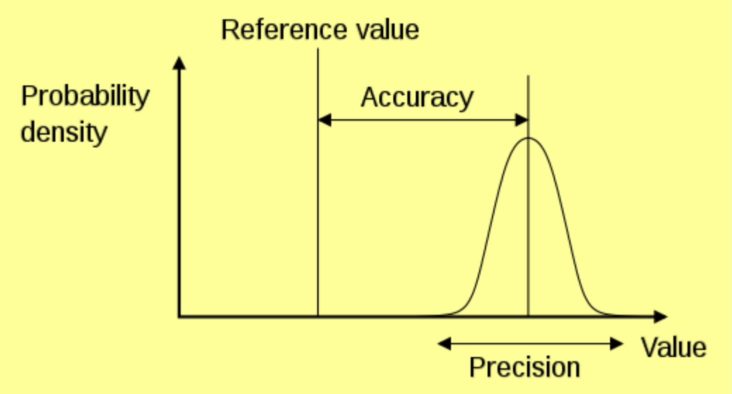
  - **<u>Precision</u>**: *"closeness between indications of measured quantity values"*

    ➔ Repeatability

  - **<u>Accuracy</u>**: *"closeness between a measured quantity value and a true quantity value"*

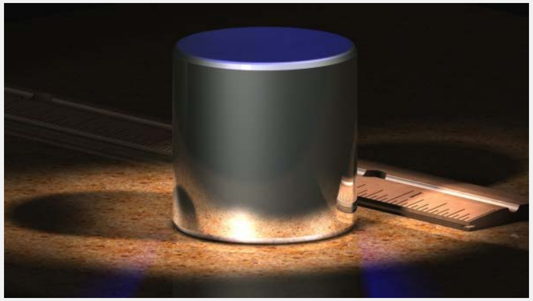
    ➔Trueness + precision

    ➔Accurate system = small measurement errors (due to systematic effects)

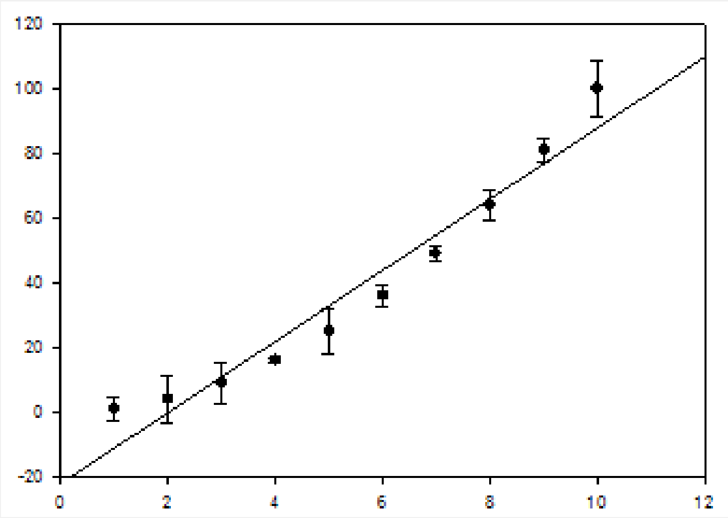


Metrology and terminology (3/3)

- **Calibration:** operation providing as an end-result
  - a <u>relation between measured values and reference </u>ones: mathematical model ; curve ; table
  - associated measurement <u>uncertainties</u>
  - a <u>correction</u> of the indicated quantity value



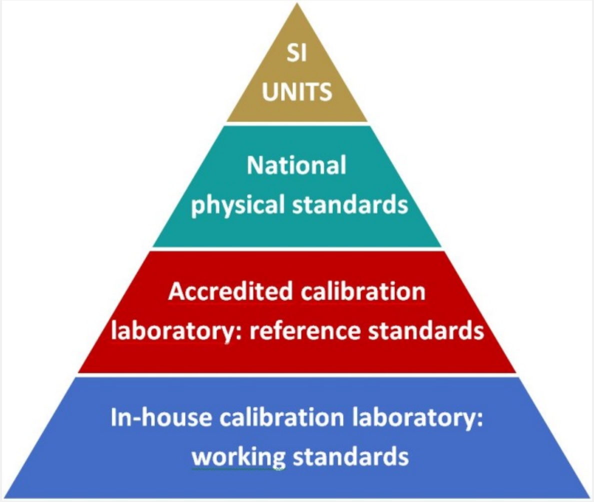
Instruments impacted by calibration are all apparatus with a requirement for metrological traceability in the SI i.e. instruments affecting the quality of a measurement or needing corrections of the raw measurements.



- **Uncertainty:** *"non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand"*
  - an indicator of the quality of a measurement
  - methods: GUM ; Monte-Carlo ; Bootstrap

Why the need for lidars calibration? (1/2)

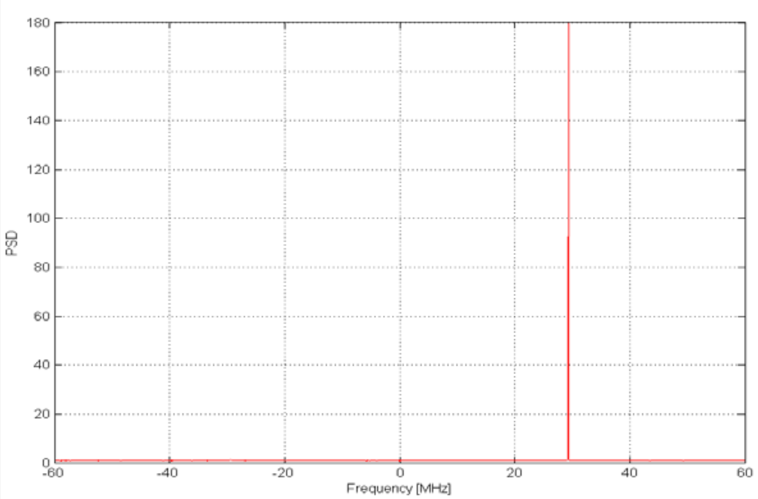
- **IEC standards (64100-12-1)**
  - Traceability is:
    - Required for certification: power curves, loads
    - Provided by a **calibration**



- **Individual calibration of lidars components?**

electronical, optical and mechanical parts:
  - separate conformity certificate:
  - BUT the raw measurand is a time domain of el. current (photo diod)

➔ Doppler frequency spectrum (processing)

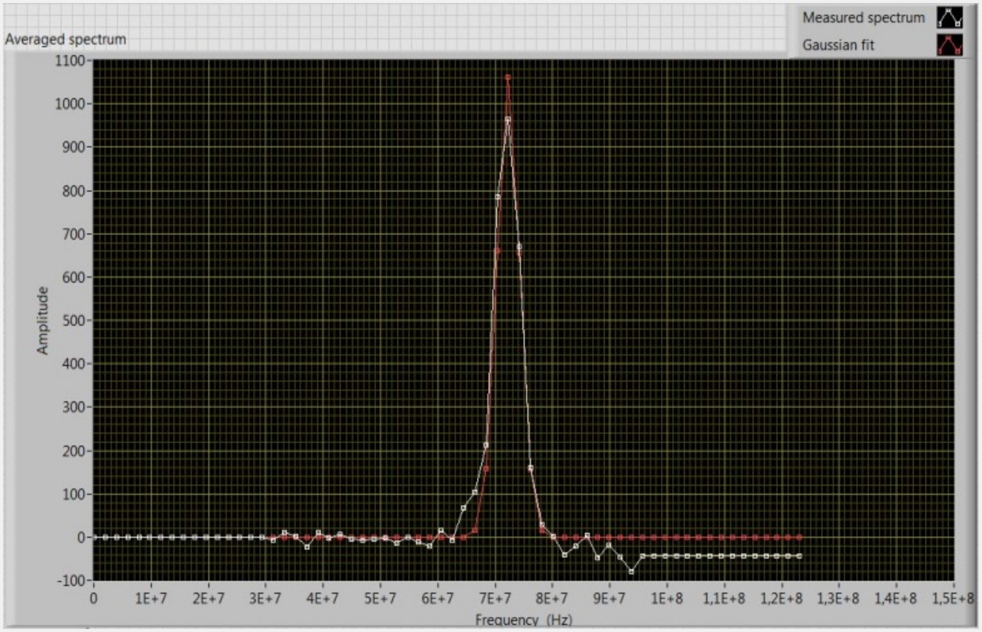


- **In-house calibration:**
  - lidars manufacturers procedures
  - at DTU: rotating wheel
    - ➔ precise and accurate reference speed
    - ➔ however, unrealistic frequency spectrum (very narrow peak, Dirac)

Why the need lidars calibration? (2/2)

- **Field calibration: similarity of operational conditions**
  - a calibration should be performed in similar measurement conditions to the ones for which a measuring system is intended to be used
    - Wind speed range
    - Physical range (distance)
    - operational conditions:
      - ➔ turbulence, shear, veer
      - ➔ possible terrain effects
      - ➔ thermal stability

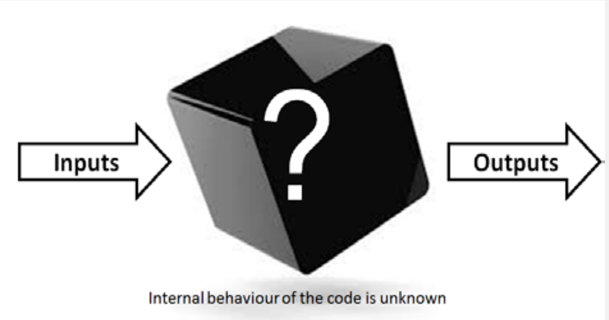
- **"real-world" spectra analysis:**
  ➔ measurement accuracy of the Doppler frequency?



Black & white box calibration of lidars

Two different principles

- **Lidar measurand and outputs**
  - Measurand: frequency of the backscattered light
  - Converts it into a Radial Wind Speed, i.e. the **component of the wind vector in the line of sight** (LOS, laser beam direction)
  - RWS considered as the ”raw measured quantity”
  - Output parameters
    - obtained by applying mathematical models to a number of RWS measurements ➔ reconstruction algorithms
    - Examples: HWS, shear, wind direction, …



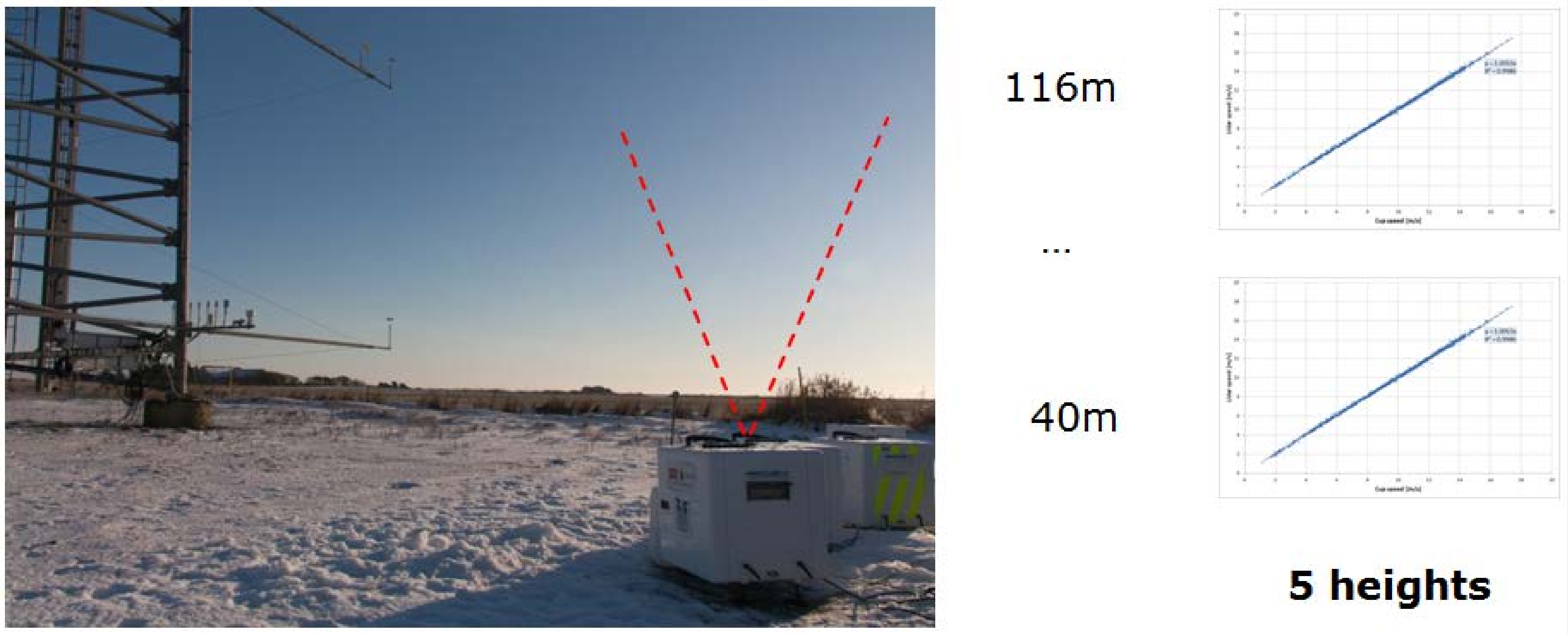
- **Two principles**
  - Black box: calibration of the ”mathematically derived” parameter against the same type of parameter measured by a reference instrument
    ➔ e.g. HWS vs. Cup anemometer wind speed
  - White box: calibration of the parameters used as inputs to the reconstruction algorithm
    ➔ individual beam RWS calib

Example of a black box calibration

Ground-based lidar calibration: Wind Cube

- **Example: calibration of ground-based profiling lidars**
  - Measurand: horizontal wind speed
  - Reference: cup anemometers at several heights

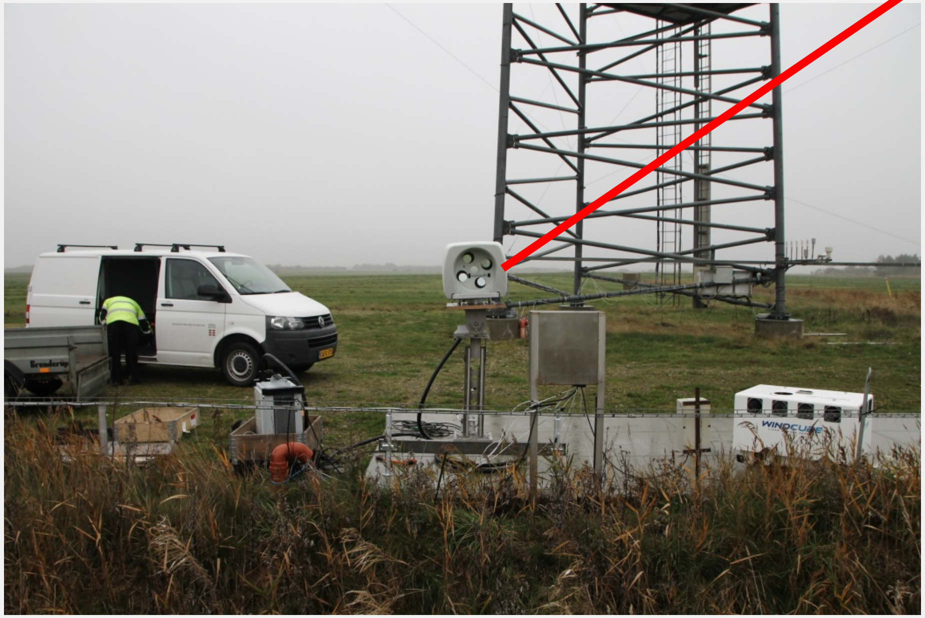
DANAK
CAL. Reg. no. 363

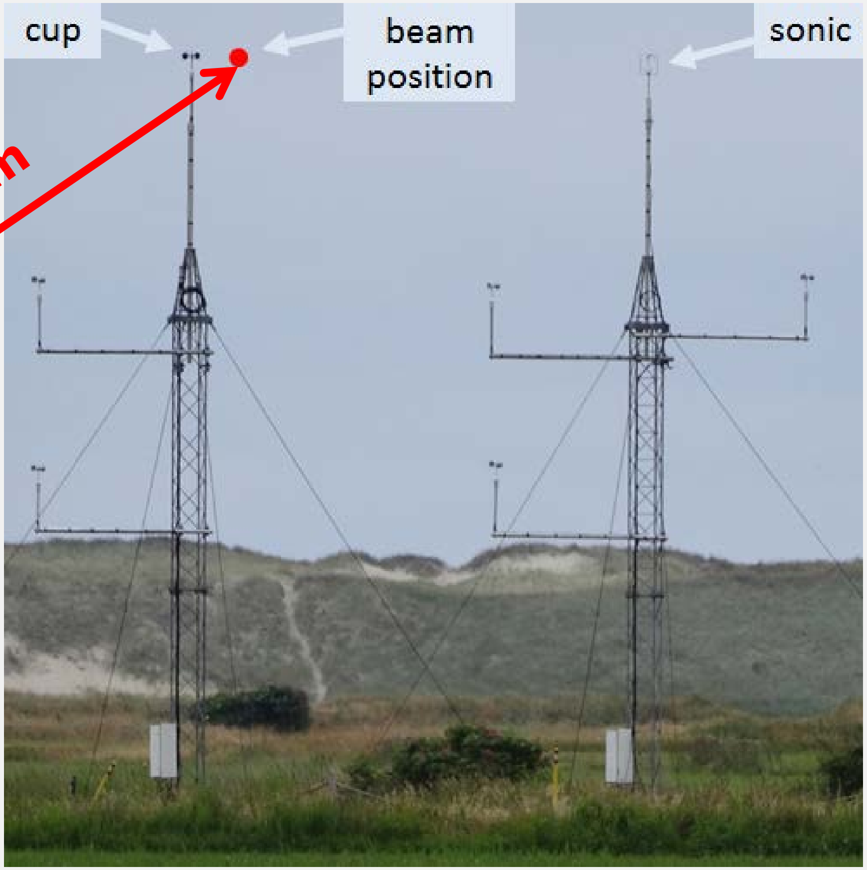


Example of a white box calibration

RWS calibration

- **Test site: Høvsøre**
- **Setup:**
  - Two small masts $\mathrm{h} = 8{,}90m$
    - Top mounted cup anemometer
      ➔ horizontal wind speed
    - Top mounted sonic anemometer
      ➔wind direction





Calibration procedures

White box example: RWS calibration

1) Calibration of internal inclinometers

2) Geometry verification

– i.e. all ”fixed” parameters that can be used in reconstruction algorithms

– e.g. cone / half-opening angles

– Blocking / unblocking process

➔ CNR ; IR imaging

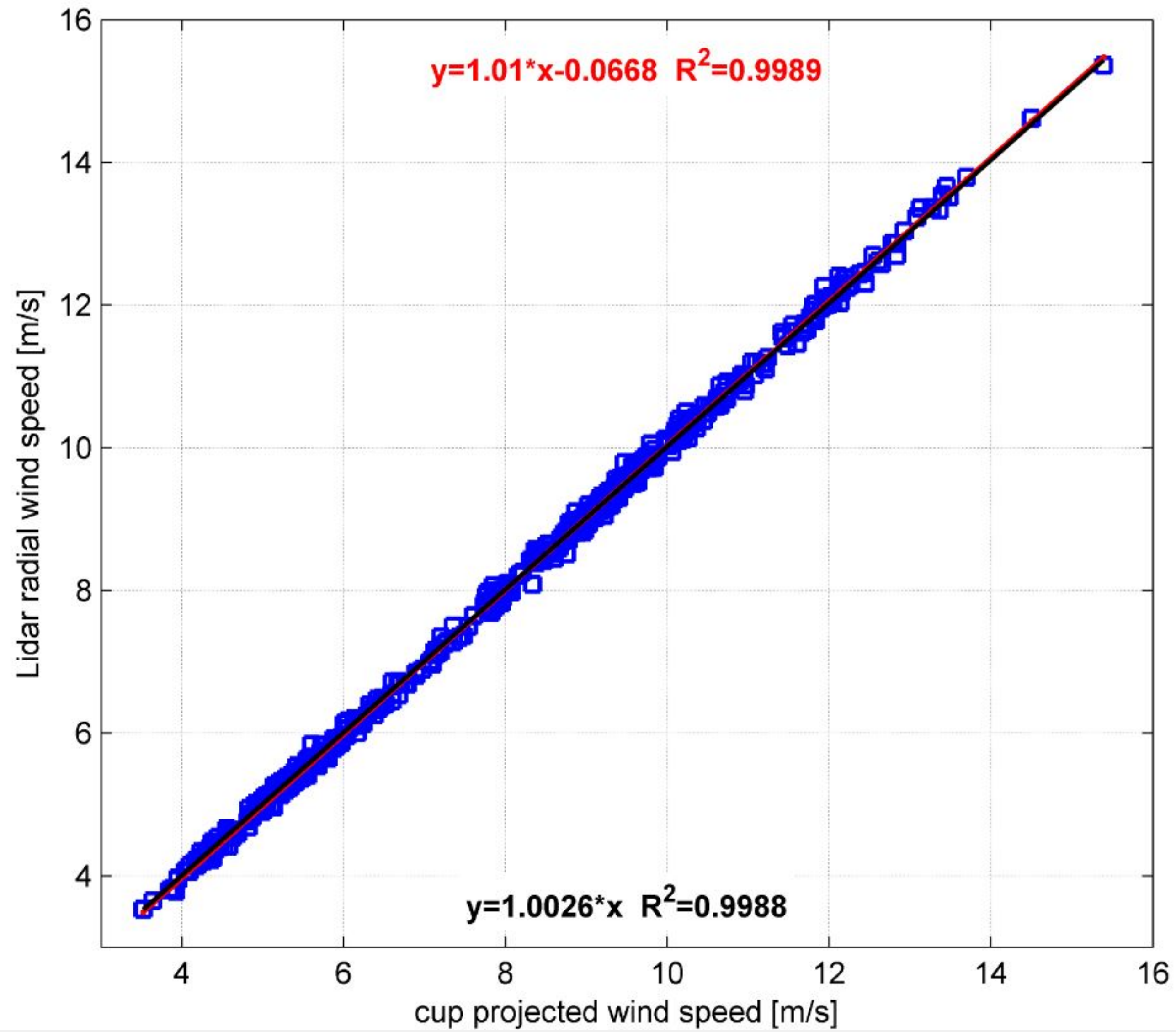
3) LOS direction evaluation

4) RWS calibration

$$WS_{ref\ projected} = HWS_{cup}.\cos(WD_{sonic} - LOS_{dir}) \cdot \cos(tilt)$$

Calibration procedures

White box example: RWS calibration



Black & white box calibration of lidars

Pros & cons

	Black box	White box
Requirements	• Reference instrument available & calibrated	• Geometry check • Being able to calibrate the RWS • Reconstruction algorithms ➔ Access + verification
Pros	• Direct comparison	• Physically existing quantity • Uncertainty derivation of ANY reconstructed output
Cons	• Need for multiple ref. instrument • Assumptions • Reconstructed outputs can physically not exist!	• Longer calib. duration (~ 5-6 weeks / beam)

Measurement uncertainties

- **Expressed for each 0.5 m/s bin**
- **Uncertainty sources (cf. GUM method)**
  - Reference wind speed (cup): preponderant source
  - Reference wind direction (sonic)
  - LOS direction estimation / LOS elevation / Flow inhomogeneity in the probe volume / Mean RWS deviation
  - Statistical uncertainty in the RWS measurement

TOTAL uncertainty: $U_{RWS} = \sqrt{\sum U_i^2}$ ➔ $\sim 1 - 2\%$ / bin

- **Combining uncertainties of individual RWS**
  - Uncertainty on ANY reconstructed output through the algorithm using either GUM or Monte-Carlo
  - e.g. HWS… but also wind direction, shear, veer
- **Question to be answered:**
  - should the lidars be corrected?

    ➔ the correction reduces the measurement uncertainties…

Black or white questions?